**Y-12**

**OAK RIDGE Y-12 PLANT**

**Y/IMS-00017**

# Synthesizing R&D Data: Experiences from the Integrated Manufacturing Technology Roadmap (IMTR) Project


Mary Ann Merrell
Information Management Services Division


May 5, 1999


Preprint for submission to
Inforum '99
Oak Ridge, Tennessee
May 5-6, 1999

Prepared by the
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 37831
Managed by
Lockheed Martin Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
Under contract DE-AC05-84OR21400


**MANAGED BY LOCKHEED MARTIN ENERGY SYSTEMS FOR THE UNITED STATES DEPARTMENT OF ENERGY**

Abstract:

IMTR is a tremendous undertaking to assess the current state and future needs of Manufacturing Technology R&D. A follow-on project to the roadmaps is the development and populating of a Gap Analysis database containing current R&D abstracts related to the roadmaps' technical elements. Efficiently identifying the R&D projects within scope presents many travails of synthesizing data from across a wide spectrum. Challenges to this project were directly proportional to the lack of single-source data collections.

Biographical Information:

Mary Ann Merrell is an Information Management Analyst with Information Management Services Division, Lockheed Martin Energy Systems, Inc., Oak Ridge, TN. Her primary activities through IMS' Information Brokering Services are in information retrieval and analysis supporting business development activities across the company. She holds an MBA and an MLIS.

**INFORUM '99**

**_______ *RELEASE STATEMENT***

To: The Office of Scientific and Technical Information

From: Mary Ann Merrell

Title of Paper: Synthesizing R&D Data: Experiences from the Integrated Manufacturing Technology Roadmap (IMTR) Project

__x_ I verify that the paper I have submitted for InForum '99 has been reviewed to ensure that it contains no sensitive, proprietary, or other information inappropriate for public release and therefore is appropriate for broad access on an open system.

___ I cannot verify that the content is appropriate for public release.

| | |
|---|---|
| Mary Ann Merrell | 3/25/99 |
| Signature | Date |

# Synthesizing R&D Data: Experiences from the Integrated Manufacturing Technology Roadmap (IMTR) Project

## *INTRODUCTION*

Ten years ago, who would have envisioned a world around the corner in which cellular phones ringing in grocery store checkout lines would be commonplace, where working concurrently on engineering design specs with a cohort across the country would be de rigueur? What visionaries amongst us could foresee much of the technologically commonplace in our lives today – parents checking in on their children at daycare via the Internet, electronic books for travelers weary of turning conventional paper pages?

Underlying all of these advancements, the state of manufacturing has been and is being constantly barraged by the effects of rapidly, ever changing manufacturing requirements and technological advancements. New customer needs, facets related to the competitiveness of the U.S. manufacturing sector, and emerging technologies are forcing an unprecedented level of change in the processes, equipment and systems that are used to design and produce virtually every product encountered daily.

Everyone involved in the manufacturing process from the research organization to the product vendor has a stake in riding into a transformed manufacturing era. But to do so intelligently and armed with the right information is the great enabler. One of the key tools capable of supporting successful negotiation of the future technology maze is a tool that supports defining and assessing strategic direction to maximize potential gains – the Technology Roadmap. A Technology Roadmap is a time-based plan that defines technology goals and supports a focused effort to achieve those goals. Many industries, most notably the Semiconductor Industry and many DOD sectors, have long utilized technology roadmaps that address their unique vision. However, there has never been a parallel effort to evaluate cross-cutting manufacturing infrastructure needs that affect and span multiple industry sectors until now.

## *OVERVIEW OF THE INTEGRATED MANUFACTURING TECHNOLOGY ROADMAP PROJECT*

The Integrated Manufacturing Technology Roadmapping Initiative (IMTR) was created from an acknowledged need to identify and evaluate the key technology goals that will enable a competitive and capable manufacturing base in the future. There was also a parallel need seen to identify the technologies with broad application across multiple U.S. manufacturing sectors. Finally, there was a need to create pathways for achieving the technology goals delineated as critical to the future solidity of the U.S. manufacturing base. Four federal agencies recognized the value of such an effort; IMTR is currently being sponsored by the National Institute of Standards and Technology (NIST), the U.S. Department of Energy, the National Science Foundation and the Defense Advanced Research Projects Agency (DARPA).

These key organizations clearly saw the need to support the development of cross-cutting roadmaps. Whereas no single company would be willing to fund such a project and then share the results with their industry sector peers nor would a single industry take the initiative, the neutral position of the agencies supporting IMTR provided the support needed to fund such broad-based strategic visioning work. Before IMTR, no comprehensive plan existed that defined the critical manufacturing technology goals that potentially affect all manufacturing sectors; and no plan existed that provided a structure for creating a concentrated call to action to pursue goals for assuring a strong manufacturing infrastructure in the future. So, not only was IMTR tasked with identifying the technology pieces, IMTR was also tasked with becoming a change agent.

One of the key changes is the recognition of the necessity for greater collaboration. The complexity of the manufacturing process often means that optimal solutions are beyond the individual manufacturer's ability; thus a new paradigm of leveraged solutions will be needed in 21st century manufacturing. The enhancement of an environment that will support collaborative R&D has long been identified as a key to the future stability of the manufacturing sector. No longer can most individual companies and organizations shirk the costs of duplicate research or afford all of the intelligence and equipment necessary to be financially successful manufacturers in the future. The foundation afforded by the work of the IMTR can enable manufacturers to achieve critical technology goals while supporting the movement of R&D from the laboratory to industry. Not surprisingly, this focused collaboration translates to additional benefits of reducing the risks and costs of manufacturing innovation for all participants.

***THE CHALLENGES OF THE INTEGRATED MANUFACTURING TECHNOLOGY ROADMAP PROJECT***

IMTR has focused on four key inter-related areas critical to the infrastructure necessary for future manufacturing technology requirements. These areas were identified in many precursor assessment activities, including the Next-Generation Manufacturing (NGM) project, which evaluated the needs of government and industry R&D in critical areas that affected the entire spectrum of manufacturing activities. Whereas NGM assessed all attributes of the manufacturing enterprise including business, customer and global market issues, IMTR was tasked to focus on the key technology-related goals that cut across industry.

To create the roadmaps, the IMTR project team and their sponsors enlisted a broad range of activities to gather input. Workshops were held across the country designed to garner public and private sector input. Surveys were posted on a wide variety of manufacturing-related listservs and select web sites such as IndustryNet.com. Existing roadmaps were scrutinized to identify cross-cutting industry needs. In the workshops alone, more than 400 people representing more than 150 companies and universities participated; this resulted in a broad base of input to the roadmaps. Draft documents were posted on the IMTR web site throughout the creation process in order to gain critical feedback during revision stages

The IMTR project team has now published individual technology roadmaps for each focus area which are available at the IMTR web site, http://imtr.ornl.gov. The documents are:

- Information Systems for Manufacturing
- Modeling and Simulation
- Manufacturing Processes and Equipment
- Enterprise Integration

The roadmaps reflect the U.S. manufacturing industry's Grand Challenges which identifies the superjacent needs of the future including the creation of totally integrated enterprises, enabling foundations for future manufacturing, zero life-cycle waste processes, and support of integrated product realization. Flowing down from the Grand Challenges, each roadmap presents a high-level plan for the technologies that are required to enable the competent manufacturing enterprises of the future. These high-level visions, IMTR 2015 Vision, are defined with supporting goals, requirements and tasks necessary to successfully enliven the vision. In addition, "nuggets" were identified; these are overriding capabilities that will have major impact and afford favorable returns on investments to organizations and industry when solved. The resulting roadmaps define more than 200 Goals, 400 Requirements, and 700 Tasks that will markedly affect the future of manufacturing.

The complexity of the roadmaps can be seen when recognizing the level of detail each topic encompasses. Each roadmap has more than 35 goals. As an example of the level of detail associated with just one goal, the following excerpt was taken from the <u>Information Systems for Manufacturing Enterprises Technology</u>

Roadmap. This particular goal is matched to the Information Systems nugget, "Mature Integrated Product/Process Development." Related to this goal is the following:

[From Technology Area: 2.3 Product Design, Definition, & Data Interchange]

***Goal:***
2.3.3 Product Information Bridging
***Vision:***
Product information shared and accessed by all users and tools throughout the product life-cycle

***Requirements:***
2.3.3.1 Real-time, Global, Collaborative Product Design
2.3.3.2 Transferability and Associativity of Production Data
2.3.3.3 Collaborative Information Sharing by Enterprise Partners

***Tasks:***
2.3.3.3.1 Seamless Product Data Exchange
2.3.3.3.2 Global Real-Time Data Sharing/Exchange
2.3.3.3.3 Data User Requirements Identification
2.3.3.3.4 Protection of Proprietary Information
2.3.3.3.5 Supply Chain Tools for Digital Exchange
2.3.3.3.6 Extracted Data Translation
2.3.3.3.7 Information Exchange of "Deltas"
2.3.3.3.8 Product Design Workflow

***THE IMTR GAP ANALYSIS***

A key follow-on activity to the roadmaps was the task to assess the current state of manufacturing R&D activities that are described in the roadmaps. Merely knowing the technologies required for the future is insufficient to be able to cogently put resources in place to assure that the technology goals are met. Where are the R&D voids? What are the R&D areas where little research is being conducted? Or, conversely, what are the R&D areas in which current R&D activities are being heavily supported? The process of identifying relevant R&D projects and mapping these to the roadmaps became known as the Gap Analysis.

Included in the Gap Analysis project team were staff from across the Oak Ridge complex: Oak Ridge Centers for Manufacturing Technology, Y-12 Development Division, Data Systems Research and Development Division (DSRD), and Information Management Services (IMS) as well as participants from the private sector. This phase of the IMTR project began in October 1998; the analysis created from the data was presented to the project sponsors in April 1999.

A database was designed to capture a substantial number of data elements in order for the Gap Analysis to be able to provide a comprehensive evaluation. Database fields included generic project information (such as Title, Abstract, and Point of Contact information) as well as more pointed information (Funding Levels, Funding Organizations, Industry Sector, and Partner Organizations). The database was created in Microsoft Access '97; reports were generated with Crystal Reports 7.0.

Project abstracts were sent to technical reviewers who were responsible for determining whether or not the project's technology elements were related to one or more of the roadmaps' goal, requirement, or task areas. If the project was in-scope, the reviewer was responsible for mapping the technology elements to the specific, lowest level entity possible in the roadmap. Each project could be mapped to multiple IMTR elements. In addition to mapping to an element, each IMTR mapping was further evaluated on two additional indices. Rankings were given on a scale of 1-5 on the Maturity and the Applicability of the individual IMTR element. Reviewers were also responsible for identifying the relevant Industry Sector(s) applicable to the project as a whole.

The Maturity Ranking assessed the timeframe in which the technology element is/would be available, evaluated how comprehensive the technology element being considered addressed the IMTR element and also factored how well the technology development plan addressed minimizing risk. The Applicability Ranking assessed the breadth of use of the technology element relative to the industry sector(s) defined.

### *THE FIFTH GRAND CHALLENGE - IDENTIFYING RELEVANT PROJECTS FOR REVIEW*

The search for abstracts applicable to the technical review process was a challenge that was directly related to the lack of a single or primary information resource; the challenge was also directly related to the wide variance in the depth of information included in abstracts by the information providers. The search topics were undeniably broad with over 700 defined technology areas to encompass in the search; however, the requirement that the R&D activities for review be cutting edge as opposed to well-entrenched applied R&D narrowed the search focus into a more manageable universe. In some sources, that focus could be narrowed to the current year only or current plus two years. Little relevant data would be located that would be published greater than three years past.

Some typically rich sources for data, especially for federally-funded data such as NTIS and ReconPlus, often included abstracts that were not descriptive or detailed enough to be evaluated. The technical reviewers were chosen for this task specifically because of their depth of knowledge and could rate many abstracts that had very little substance because of their familiarity with the work; yet, many traditional sources were not useful and abstracts came back marked “Insufficient Data.” It was not an uncommon occurrence when the last line of an abstract read, “The results of this study are presented in this report.” Because of time constraints, there was not sufficient time to search further to locate additional information for abstracts that sounded promising but offered insubstantial description of the R&D.

In addition to the lack of concise abstracts, most of the sources lacked many of the data elements that were originally sought. Abstracts without open/close dates for the research were commonplace; abstracts without mention of the funding or research partners were not rare. Most included no funding information at all, or if included was often quite difficult to decipher. Was it funding for that funding cycle, total funding, or was it the organization’s cost shared portion? Again, because of time constraints, there was not time to track back to each project sponsor to obtain complete information were it available in the first place. A notable exception to all of these deficiencies was the NSF Grants and Awards Database available via the NSF web site. This resource offered the breadth of data elements required combined with an adequate search interface and the ability to download multiple records.

Search engines became a critical element in the ability to lasso relevant data; yet, search strategies often resorted to the lowest common denominators of standard practice. Most web-based resources offer minimal search functionality centered on basic delimiters for keyword or title descriptors combined with a sparse scattering of other search options. Searching such a wide range of topics also meant that many search engines could not support the search as a single search statement and so redundant data often appeared in later search sets. In addition to the lack of flexibility of some sites, many web resources required the pain-staking requirement of reviewing and saving search results one by one or page by page. Several information providers, especially the DOD SBIR/STTR Awards Database and several of the Navy ManTech centers, offered alternative sources for the data when contacted. In one case, an NSF Engineering Research Center actually sent their original copy of the data used for their web-based report on a disk they retrieved from their publications department.

The lack of a single source of data translated to an ever-changing search strategy as more resources were searched. Although the Gap Analysis database was designed to be able to identify duplicate titles or duplicate report numbers when entering data, one of the key search strategy goals was to circumvent reviewers needlessly evaluating projects that had been previously assessed. Search strategies often included as many NOT statements as OR statements in an attempt to remove the possibility of redundant data being reviewed. Each in-scope project required a minimum of 20 minutes to review and identify the mappings; therefore, the costs associated with duplicate records would have been significant. At the end of the data review phase for the Gap Analysis, the database had over 1,600 records of reviewed abstracts; a total of 15 duplicate projects were removed from the database.

One of the great strengths of commercial online vendors was the ability to do a single search across multiple databases; the notion that information searchers can define one search and pull results from dozens or hundreds of different databases at once, removing duplicates, ranked by relevance, is the ultimate tool. But, many information providers are quickly moving away from third-party access as they build individual web sites to provide access to their data. Current web search engine technologies are woefully far behind the ability to adequately filter the realms of data daily deluging the Internet. In the Gap Analysis, the in-scope data was fairly equally distributed between Internet sites and commercial vendors; the combination of resources was required to provide the balanced data needed. The search universe is far from having the ability to search across such diverse platforms.

## *THE FUTURE OF IMTR*

The IMTR project team is currently undertaking the creation of a composite document that will synthesize the four technology roadmaps. In addition, several “Tier Two” workshops and documents have been identified from areas noted of particular import in the roadmap activities. Activities are also focused on inhabiting a Coordinating Council of recognized government and industry leaders to champion the implementation of IMTR; an Inaugural Meeting is scheduled for June, 1999.

The original design for the extended use of the Gap Analysis data was to develop a web interface and move the data from Access into an SQL application. The Access environment allowed for an adequate tool to collect the data that was a familiar and affordable application to all members of the Gap Analysis team. Moving the data would allow readers of the web-based roadmaps to be able to access the data. Online readers could view projects related to the specific area of the roadmap as they walk through different technology areas. In addition, the interface was intended to allow visitors to the web site the flexibility to be able to keyword search through the project abstracts to identify R&D activities of interest. Because of the breadth of data that was imported into the database, viewers could identify key organizations performing work, program contacts, determine industry sector involvement and evaluate areas of high and low R&D activity. These functionalities related to public access of the Gap Analysis data are still being negotiated.

## *CONCLUSION:*

The IMTR project and the Gap Analysis database in particular offer an insight into the tremendous potential of gathering data from across the information resource universe. However, it is not merely the acquisition of the data that has created a tool of merit. Without the involvement of the technical reviewers to assess the content, this data would be more akin to a bibliography than the power tool it has the potential to be. The usefulness of collating and synthesizing the data can not be understated. The roadmaps become theory without practice for they become an outline with little relevance to concrete planning or determined action without this accompanying snapshot of the state of current U.S. manufacturing R&D activities. Therein lies the power of the analysis; it supports insights into the variance of activities between technology areas, identifies current funding levels across multiple sponsors, highlights organizations active within certain technical element areas, and provides a host of other indicators. The roadmaps sans the Gap Analysis would provide little direction to those with the most to gain from their intelligent use.

***APPENDIX A: SOURCES***

PROJECT DATA INFORMATION RESOURCES:
BIBLIOGRAPHY OF SOURCES

Advanced Technology Program Funded Projects. National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce. Online at http://www.atp.nist.gov/www/comps/allbriefs.htm. Search date: 9/98, 11/98.

Agile Manufacturing Program Case Studies. Agile Manufacturing Initiative, Defense Advanced Research Projects Agency (DARPA), Department of Defense, and the National Science Foundation (NSF). Data provided by the DARPA Defense Sciences Office (DSO). 1998. To be published Spring 1999.

AGRICOLA (AGRICultural OnLine Access) (Database). National Agricultural Library, U. S Department of Agriculture. Search date: 10/98.

AIAG's Accomplishments. Automotive Industry Action Group. Online at http://www.aiag.org/about/. Search date: 9/98.

Aluminum Industry Abstracts (Database). Materials Information, Cambridge Scientific Abstracts. Search date: 10/98.

Best Manufacturing Practices Database. Office of Naval Research U.S. Navy. Online at http://www.bmpcoe.org/search1/bestpractices.html. Search date: 10/98.

BIOSIS (Database). Biological Abstracts and BioResearch Index. BIOSIS. Search date: 10/98.

CASI Technical Report Server (RECONselect)Database. National Aeronautics and Space Administration (NASA) Center for AeroSpace Information. Online at http://www.sti.nasa.gov/RECONselect.html. Search date: 1/99.

CEC Projects & Pilots. Center for Electronic Commerce, Environmental Research Institute of Michigan (ERIM). Online at http://www.erim.org/cec/projtxt.htm. Search date: 9/98.

Ceramic Abstracts (Database). Materials Information, Cambridge Scientific Abstracts. Search date: 10/98.

Current CECMT/GLCC Programs. GLCC, Inc., Navy Center of Excellence for Composites Manufacturing Technology (CECMT), U.S. Navy. Online at http://www.glcc.org/programs.html. Search date: 1/99.

DOE Research & Development Project Summaries. Office of Scientific & Technical Information, U.S. Department of Energy. Online at http://www.doe.gov/rnd/dbhome.html. Search date: 10/98.

Defense Technical Information Center Technical Reports Database. Defense Technical Information Center, Defense Information Systems Agency, Department of Defense. Search date: 9/98.

EI Compendex (Database). Engineering Information, Inc. Online at http://www.ei.org (subscription only). Search date: 9/98.

Electronics Agile Manufacturing Research Institute (EAMRI). Rensselaer Polytechnic Institute. Online at http://www.eamri.rpi.edu/html/projects.html. Search date: 10/98.

EMPF Technical Publications. Electronics Manufacturing Productivity Facility (EMPF), U.S. Navy. Online at http://www.cieem.rpi.edu/dlm/aci_website/EMPF/publications/index.html. Search date: 10/98.

Energy Science and Technology (Database). Office of Scientific & Technical Information, US Department of Energy. Search date: 10/98.

Engineered Materials Abstracts (Database). Materials Information, Cambridge Scientific Abstracts. Search date: 10/98.

ETO Research and Development Project Areas. Electronics Technology Office, (ETO), Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://www.darpa.mil/ETO/RaDPrograms.html. Search date: 10/98.

Enviroline (Database). Congressional Information Service, Reed Reference Publishing Company. Search date: 10/98.

Food Science and Technology Abstracts (Database). IFIS Publishing. Search date: 10/98.

Grants and Awards Database; Award Data (Projects Funded, 1989-). National Science Foundation. Online at http://www.nsf.gov/home/grants/grants_awards.htm. Search date: 9/98.

Industrial Projects Locator (IPLocator). The Office of Industrial Technologies (OIT), Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Online at http://bwonotes5.wdc.pnl.gov/IOF.nsf. Search date: 9/98. 9/1/98.

Information Systems Office (ISO), Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://dtsn.darpa.mil/iso/. Search date: 10.98.

Information Technology Office (ITO) Research Areas. Information Technology Office (ITO), Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://www.darpa.mil/ito/ResearchAreas.html. Search date: 10/98.

Institute for Manufacturing And Sustainment Technologies (iMAST); Applied Research Laboratory, Pennsylvania State University; U.S. Navy MANTECH Centers of Excellence, U.S. Navy. Project Abstracts received from iMAST. 1998.

Institute of Textile Technology Project Abstracts. Data provided by AMTEX Laboratory Program, Y-12 Site. Additional information available online at http://www.itt.edu/itthome.htm.

Machine Tool Agile Manufacturing Research Institute (MTAMRI) Thrust Area Projects. National Science Foundation, Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://mtamri.me.uiuc.edu/mtamri/technical. Search date: 9/98.

Manufacturing Engineering Laboratory Projects and Programs. National Institute of Standards and Technology, U.S. Department of Commerce. Online at http://www.mel.nist.gov/projs.htm. Search date: 9/98

Microelectronics Lab at the University of Illinois at Urbana-Champaign.
Online at http://www.ccsm.uiuc.edu/micro/. Search date: 12/98.

MEDLINE Plus(Database). National Library of Medicine, U.S. U.S. National Institutes of Health. Online at http://www.nlm.nih.gov/databases/freemedl.html. Search date: 10/98.

METADEX (Database). Materials Information, Cambridge Scientific Abstracts. Search date: 10/98.

National Technical Information Service (Database). U.S. Department of Commerce. Search date: 9/98.

National Textile Center Annual Report, 1998. National Textile Center University Research Consortium. CD-ROM. Also available in paper and online at http://ntc.tx.ncsu.edu/html/PDFindex.html. November, 1998.

Navy MANTECH 1998 Project Book. Navy Manufacturing Technology Program, U.S. Navy. Online at http://mantech.bmpcoe.org/book/. Search date: 11/98.

NCEMT Technical Thrust Areas. National Center for Excellence in Metalworking Technology NCEMT), operated by Concurrent Technologies Corporation (CTC) for the U.S. Navy's Manufacturing Technology (MANTECH) Program, U.S. Navy. Online at http://www.ncemt.ctc.com/thrustAreas. Search date: 10/98.

NCMS Technology Project Portfolio. National Center for Manufacturing Sciences. Online at http://www.ncms.org/3portfolio/portfolio.htm. Search date: 9/98.

Proposed Research Projects. Agile Aerospace Manufacturing Research Center (AAMRC). Online at http://arriwww.uta.edu/aamrc/3_3_2.html. Search date: 11/98.

Research and Development Areas. Defense Sciences Office (DSO), Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://www.darpa.mil/DSO/rd/index.html. Search date: 10/98.

SBIR and STTR Abstracts and Awards Data, 1983-1998. DoD Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program, Department of Defense. Online at http://www.sbirsttr.com/Awards/Default.asp. Search date: 9/98.

SCRA Products & Services. South Carolina Research Authority (SCRA), Inc. Online at http://www.scra.org/scra-products.html. Search date: 9/98.

Technical Accomplishments Index. United States Council for Automotive Research (USCAR). Online at http://www.uscar.org/pngv/technical/index.htm. Search date: 9/98.

Technology Reinvestment Project (TRP) Archives. Joint Dual Use Program Office (JDUPO); Department of Defense Research and Engineering (DDR&E), Defense Advanced Research Projects Agency (DARPA), U.S. Army, U.S. Navy and U.S. Air Force. Online at http://www.darpa.mil/jdupo/archive.html. Search date: 12/98.

TTO Programs. Tactical Technology Office (TTO), Defense Advanced Research Projects Agency (DARPA), Department of Defense. Online at http://www.darpa.mil/tto/programs.html. Search date: 10/98.

1997 Basic Research Plan. Director of Department of Defense Research and Engineering (DDR&E), Department of Defense. Online at http://www.dtic.mil/dstp/97_docs/brp/brp.htm. Search date: 1/99.

1998 Defense Technology Objectives. Director of Department of Defense Research and Engineering (DDR&E), Department of Defense. Online at http://www.dtic.mil/dstp/98_docs/dtos/dtos.htm. Search date: 1/99.